TRENCHSTOP™ 5 S5

Infineon's low $V_{CE(sat)}$ high-speed soft-switching IGBT

Application Note

About this document

Scope and purpose

This Application Note provides some basic information and some hints on how to deal with Infineon's HighSpeed IGBT technologies and specifically the newly introduced TRENCHSTOP™ 5 S5 technology which provides unique advantages in terms of $V_{CE(sat)}$, dynamic losses, EMI figures and most important is extremely easy to use.

Intended audience

This Application Note addresses designers that intend to use TRENCHSTOP™ 5 S5 IGBT, especially in industrial and automotive applications. A minimum level of knowledge in electrical design and EMC is required.

Table of contents

1 Introduction

The efficient use of electric power is one of the main drivers for progress in power electronics. IGBT technology has supported this trend by providing application specific device optimizations. Figure 1 shows the chronological evolution of Infineon's IGBT technologies; starting from Punch Through (PT) IGBT, then introducing first Non Punch Through (NPT) IGBT, first FieldStop and Trench cell concepts [1] up to the latest TRENCHSTOP™ 5 Technology [2].

While the main market is still seen in the drives segment, other segments, focusing in the higher switching frequency ranges, gained importance and have further evolved. Among them are photovoltaics, UPS and welding applications that grew to significant size in recent years.

To respond to this increasing demand of higher switching frequency, Infineon has recently released the TRENCHSTOP™ 5 IGBT technology, especially suitable for the above mentioned field of applications.

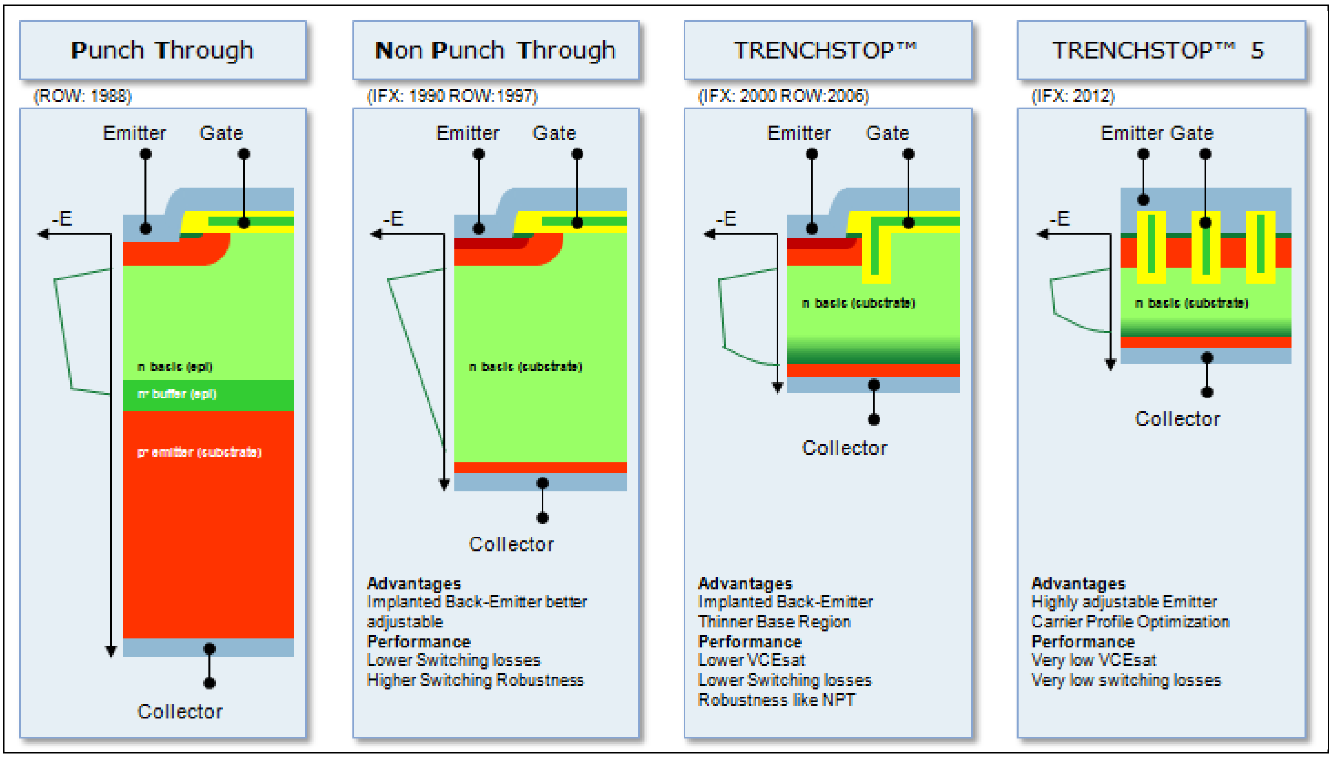


Figure 1 Chronological evolution of Infineon's IGBT technologies

1.1 TRENCHSTOP™ 5 technology

Starting from the TRENCHSTOP™ Technology, as shown in Figure 1, Infineon TRENCHSTOP™ 5 Technology allows achieving unparalleled switching frequency in the applications. This improvement has been possible thanks to the features, implemented within this new technology [1]:

- Faster turn-off capability due to high holes confinement. The holes are accumulated on the device's front side, where they have a quicker response at turn-off.
- Lower $V_{CE(sat)}$ and lower E_{on} due to high channel width, thin wafer technology and optimized doping profile.
- Optimized device input capacitance to reduce losses and to improve device controlability in high switching frequency hard switching conditions.

TRENCHSTOP™ 5 IGBT technology is divided according to Figure 2.

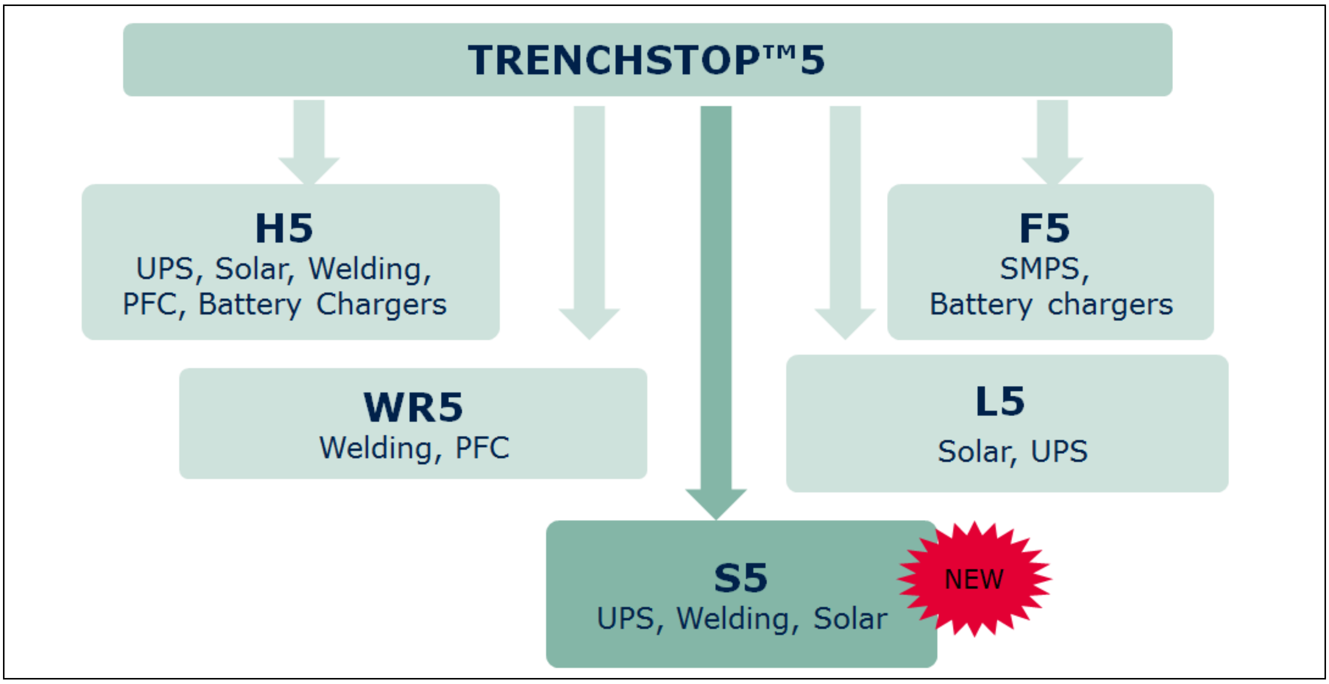


Figure 2 TRENCHSTOP™ 5 IGBT family

The main characteristics of the different products and general advice on most suitable applications are listed in Figure 3.

S5 is the latest TRENCHSTOP™ 5 IGBT version which combines low $V_{CE(sat)}$ and competitive switching losses. It is recommended for UPS, welding and solar converters.

TRENCHSTOP™ 5				
L5 IKW30N65EL5	**S5** IKW40N65ES5	**H5** IKW40N65H5	**WR5** IKW40N65WR5	**F5** IKW40N65F5
Ultra low saturation voltage for low switching frequency	Ease of use – high efficiency IGBT with low $V_{CE(sat)}$ for medium range f_{sw}	Highest efficiency IGBT for high f_{sw} and low inductance designs	Cost oriented TRENCHSTOP™5 w/monolithically embedded diode	Ultimate performance for ultra high switching applications
Optimised for switching between 50Hz and few kHz	Optimised for switching between 15kHz and 40kHz	Optimised for switching between 15kHz and 80kHz	Suitable for resonant or ZCS. Switching freq. between 20kHz and 100kHz	Optimised for switching between 20kHz and 120kHz
$V_{CE(sat)}$= **1.04V** at 175°C	$V_{CE(sat)}$= **1.60V (*)** at 175°C	$V_{CE(sat)}$= **1.95V** at 175°C	$V_{CE(sat)}$= **1.65V** at 175°C	$V_{CE(sat)}$= **1.90V** at 175°C
E_{off} = **2.18mJ** 150°C, 10Ω, 15V	E_{off} = **0.76mJ** 150°C, 10Ω, 15V	E_{off} = **0.55mJ** 150°C, 10Ω, 15V	E_{off} = **0.52mJ** 150°C, 20Ω, 15V	E_{off} = **0.48mJ** 150°C, 10Ω, 15V

Figure 3 Details of the different TRENCHSTOP™ 5 IGBT versions

A rough indication on the typical switching frequencies regarding the different TRENCHSTOP™ 5 IGBT versions is depicted in Figure 4.

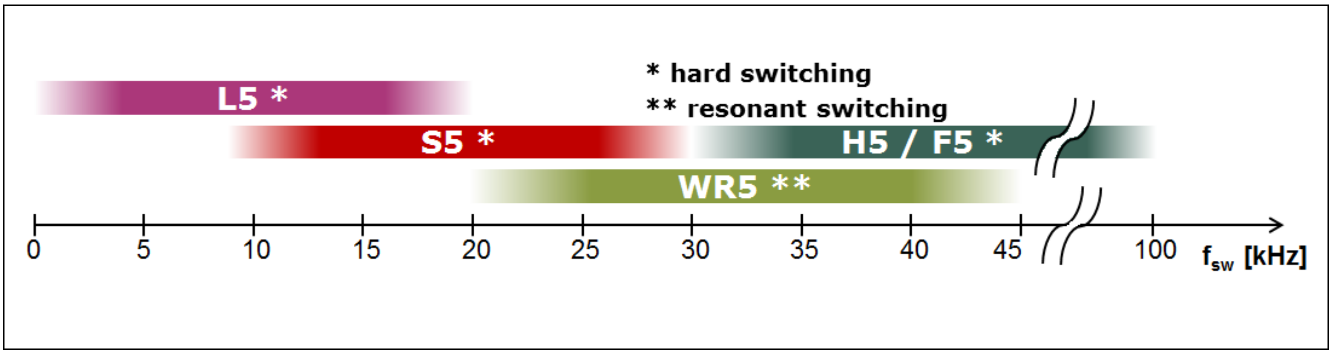


Figure 4 Recommended use of TRENCHSTOP™ 5 IGBT versions according to switching frequency

1.2 Infineon's TRENCHSTOP™ 5 discrete IGBT product offer

Figure 5 describes the nomenclature of Infineon's TRENCHSTOP™ 5 IGBTs. TRENCHSTOP™ 5 H5, F5 and WR5 IGBT product portfolio and Table 2 list the product portfolio of the TRENCHSTOP™ 5 IGBT.

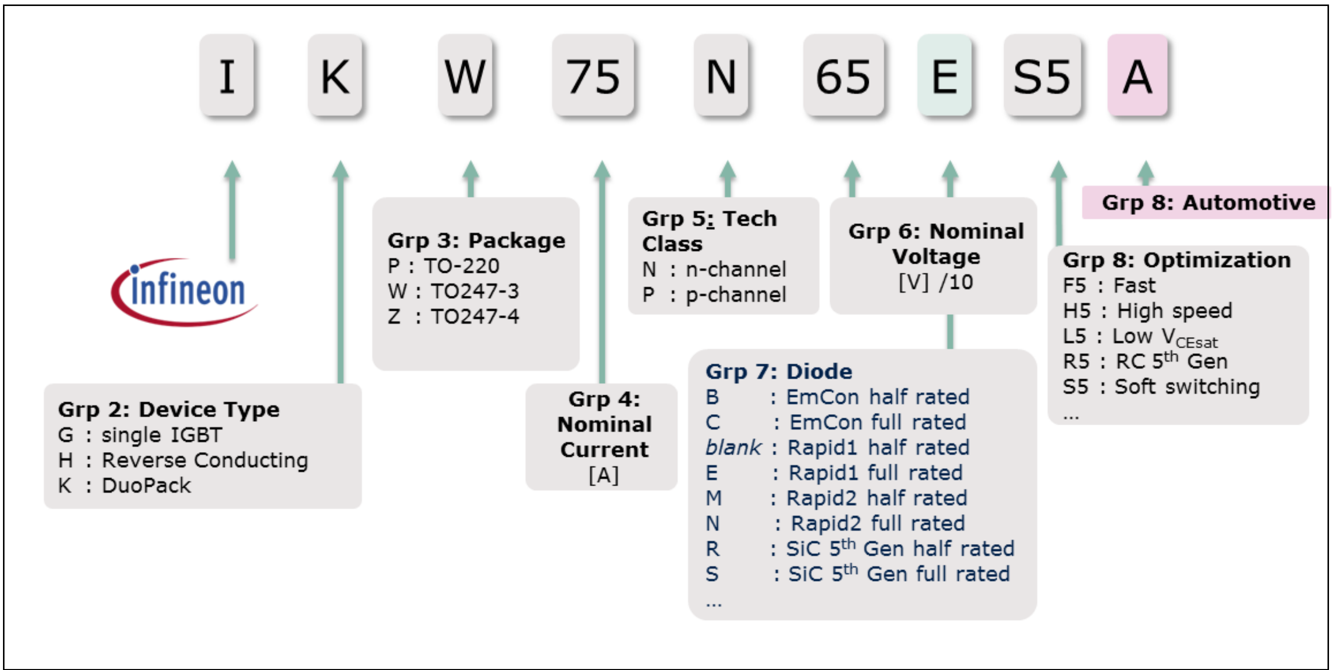


Figure 5 Nomenclature of the TRENCHSTOP™ S5 IGBT version

Table 1 describes the H5, F5 and WR5 versions in the packages TO-220, TO-220 Full-Pack (TO-220-FP), TO-247 3pin (TO-247-3) and TO-247 4pin (TO-247-4). Table 2 shows the product portfolio of the S5 and L5 IGBT versions in the packages TO-247-3 and TO-247-4.

Table 1 TRENCHSTOP™ 5 H5, F5 and WR5 IGBT product portfolio

I_C [A]	TO-220		TO-220-FP		TO-247-3			TO-247-4pin
@100°C	H5	F5	H5	F5	WR5	H5	F5	H5
8	IKP08N65H5	IKP08N65F5	IKA08N65H5	IKA08N65F5				
15	IKP15N65H5	IKP15N65F5	IKA15N65H5	IKA15N65F5				
20	IKP20N65H5	IKP20N65F5						
30	IKP30N65H5	IKP30N65F5			IKW30N65WR5*	IKW30N65H5 IKW30N65EH5	IKW30N65F5	
40	IKP40N65H5	IKP40N65F5			IKW40N65WR5	IKW40N65H5 IKW40N65EH5	IKW40N65F5	
50					IKW50N65WR5	IKW50N65H5 IKW50N65EH5	IKW50N65F5	IKZ50N65EH5 IKZ50N65NH5
75						IKW75N65EH5		IKZ75N65EH5 IKZ75N65NH5

Table 2 TRENCHSTOP™ 5 S5 and L5 IGBT product portfolio

I_C [A]	TO-247-3		TO-247-4pin
100°C	S5	L5	
30	IKW30N65ES5	IKW30N65EL5 IKW30N65NL5 IGW30N65L5	
40	IKW40N65ES5		
50	IKW50N65ES5		
75	IKW75N65ES5	IKW75N65EL5	IKZ75N65EL5

Regarding TRENCHSTOP™ 5 S5 IGBT, the product portfolio with detailed technical specification of the devices available is listed in Table 3. Testing conditions are given as well.

Table 3 Detailed technical specifications of the S5 IGBT products

Product Part Number	I_C(DC) 100°C [A]	$V_{CE(sat)}$ [V]	E_{on} [mJ]	E_{off} [mJ]	Q_g [nC]	I_F(DC) 100°C [A]	Q_{rr} [µC]
IKW30N65ES5	39,5	1,35	0,56	0,32	70	39,5	0,83
IKW40N65ES5	50	1,35	0,86	0,4	95	50	1,1
IKW50N65ES5	60,5	1,35	1,23	0,55	120	60,5	1,25
IKW75N65ES5	80	1,42	1,92	0,95	164	80	1,86

Testing conditions:
$V_{CE(sat)}$: typ. values, 25°C, V_{GE}=15 V, I_C=$I_{C(DC)}$.
E_{on} and E_{off}: typ. values, 25°C, V_{CC}=400 V, I_C=$I_{C(DC)}$, V_{GE}=0/15 V, R_G=$R_{G(nom)}$, Lσ=30nH, Cσ=30pF
Q_g: typ. values, 25°C, V_{CC}=520 V, V_{GE}=15 V, I_C=$I_{C(DC)}$
Q_{rr}: typ. values, 25°C, V_{CC}=400 V, I_F=$I_{F(DC)}$, di_F/dt=-1,2kA/µs for the 30 A and 50 A, = -0,8kA/µs for the 40 A, = -1,5 A/ns for the 75 A

1.3 Description of the TRENCHSTOP™ S5 IGBT and main differences compared to other TRENCHSTOP™ 5 IGBT versions

S5 TRENCHSTOP™ 5 IGBT is the new soft switching and low $V_{CE(sat)}$ IGBT version intended to operate between 15 kHz to 30 kHz with the possibility to approach the 40 kHz range. It also features:

- Soft and smooth switching behavior, still maintaining very competitive switching performances
- Easy to use; with the new S5 IGBT it is possible to do a 1:1 replacement of the former IGBT technologies with a very low Q_g
- Very low $V_{CE(sat)}$
- Full rated fast freewheeling diode
- Improved FB-SOA, reaching 4 x $I_{C(n)}$
- 100% dynamic test performed

TRENCHSTOP™ 5 S5 exploits the same technological approach of the former H5 version, but it uses a stronger annealed backside emitter. This allows reaching a similar switching performance as the H5 IGBT, thanks to a very simple gate resistance adjustment. This is due to a much softer behavior both in turn-on and turn-off with reduced dv/dt and di/dt at nominal load and even at partial load conditions.

Although switching losses using nominal gate resistors are slightly increased in respect to the H5, the softer commutation behavior of the S5 allows using a much smaller gate resistance keeping the same voltage overshoot at turn-off in case of bad layout with large stray inductance. In such cases, it is possible to maintain similar switching losses with respect to the H5 and still get a large benefit in total losses reduction due to the significant reduction of the forward voltage $V_{CE(sat)}$ of ~18%. Compared to the 1.65 V of the H5, S5 exhibits a value of 1.35 V only.

The main differences between the new S5 IGBT version and the other TRENCHSTOP™ 5 IGBT variants suitable for industrial and consumer markets are:

WR5 It is the price optimized application specific TRENCHSTOP™ 5 IGBT for resonant applications like Zero Current Switching (ZCS) with a monolithically embedded diode. It is suitable for welding applications, Single-Phase PFC and Boost topologies, especially in Discontinuous Conduction Mode (DCM) of operation. WR5 needs a split gate resistance $R_{G(on)}$ and $R_{G(off)}$ and eventually clamping circuitry; it offers excellent performance when used in very low stray inductive environments in the range of 10 to 30 nH in both, power- and gate-path.

L5 is the extremely-low $V_{CE(sat)}$ TRENCHSTOP™ 5 IGBT offering uncomparable $V_{CE(sat)}$ value, down to 1.05V. It is a good fit in combination with Rapid 1 diodes; in general to be used in Three-Level topologies as inner switch, especially at cos(ϕ) between 0.8 and 1. It is suitable mainly for solar inverters, but might be also used in UPS systems. It can also be used as unfolding switch device in 50Hz applications like SCR and Thyristors replacement and also in the secondary inverter for Al/Mg Welding machines or even as DC circuit breaker.

H5 provides a very fast version of the TRENCHSTOP™ 5. It is intended to be used in industrial applications like welding, UPS and solar and in general addresses applications having a layout with a total stray inductance less than 30…80 nH. It is co-packed with Rapid 1 diodes and can also be used in combination with Rapid 2-diodes or with SiC Shottky Barrier Diodes (SBD) to dramatically reduce turn-on losses.

F5 Poses the ultra-fast version, best fit in combination with Rapid 2 diode or SiC SBD; it needs a split gate resistance: $R_{G(on)}$ and $R_{G(off)}$ and in general is designed for applications having excellent layout routing with a total stray inductance less than 10…30 nH.

In Table 4, the main difference in terms of characteristics between the different TRENCHSTOP™ 5 technologies are quantified specifically for a 50 A 650 V/600 V IGBT. This includes the new S5 and the former IGBT TRENCHSTOP™ technologies. This size is not available as L5 IGBT. Therefore a 30 A IGBT has been considered as reference with parameters related to the nominal current.

Table 4 Comparison Table between HighSpeed 3 IGBT Technology and TRENCHSTOP™ 5 IGBT versions

Characteristics	IGBT 3 cell		TRENCHSTOP™ 5 cell				
	IGBT3	HS3	H5	F5	L5	WR5	S5
$I_{C(n)}$ [A]	50	50	50	50	30	50	50
FB-SOA	$3xI_{C(n)}$	$4xI_{C(n)}$	$4xI_{C(n)}$*	$3xI_{C(n)}$	$3xI_{C(n)}$	$3xI_{C(n)}$	$4xI_{C(n)}$
$V_{(BR)CES}$ [V]	600	600	650	650	650	650	650
$V_{CE(sat),typ}$ @ T_{vj}=25°C [V]	1.50	1.65	1.65	1.60	1.05	1.35	1.35
$V_{CE(sat),typ}$ @ T_{vj}=125°C [V]	1.80	1.70	1.85	1.80	1.04	1.52	1.50
E_{on} @ $I_{C(n)}$, 150°C, 10 Ω, typ [mJ]	1.7	1.6	1.3	1.2	0.7	2.1	1.2
E_{off} @ $I_{C(n)}$, 150°C, 10 Ω, typ [mJ]	1.7	1.1	0.6	0.5	2.2	0.5**	0.8
SC Rating [µs]	5	5	<1	<1	<1	<1	<1
I_C(SC)	$9xI_{C(n)}$	$6,5xI_{C(n)}$	-	-	-	-	-

(*) $4xI_{C(n)}$ available for specific applications. (**) R_G=20 Ω.

TRENCHSTOP™ 5 H5 IGBT is indeed an extremely fast device in turn-off, but it requires some effort and experience in layout designs to avoid excessive voltage overshoots in turn-off and possible challenges in terms of EMC. This effort is no longer necessary when using the S5 version, thanks to the reduced di/dt in turn-on and dv/dt in turn-off which are much easier adjustable via gate resistance compared to the H5 version. Furthermore, even in non-perfect layouts, a direct replacement of HighSpeed 3 and former TRENCHSTOP™ technology is now possible.

2 S5 IGBT static performances

TRENCHSTOP™ 5 S5 IGBT reveals a very low saturation voltage, which is dramatically improved in comparison to the fast TRENCHSTOP™ 5 versions H5 and F5. The forward voltage $V_{CE(sat)}$ has been reduced from the typical 1.65 V of the H5 down to the typical 1.35 V of the S5.

A further important advantage regarding H5 and F5, which is intrinsic in the S5 technology, is the narrower $V_{CE(sat)}$ distribution. Figure 6 depicts the typical and maximum values for $V_{CE(sat)}$ of the 40 A H5 and F5 IGBT respect to the analogous 40 A S5.

From this improved characteristic derive, from static point of view, a very stable static performance and a simple and more efficient paralleling of the devices.

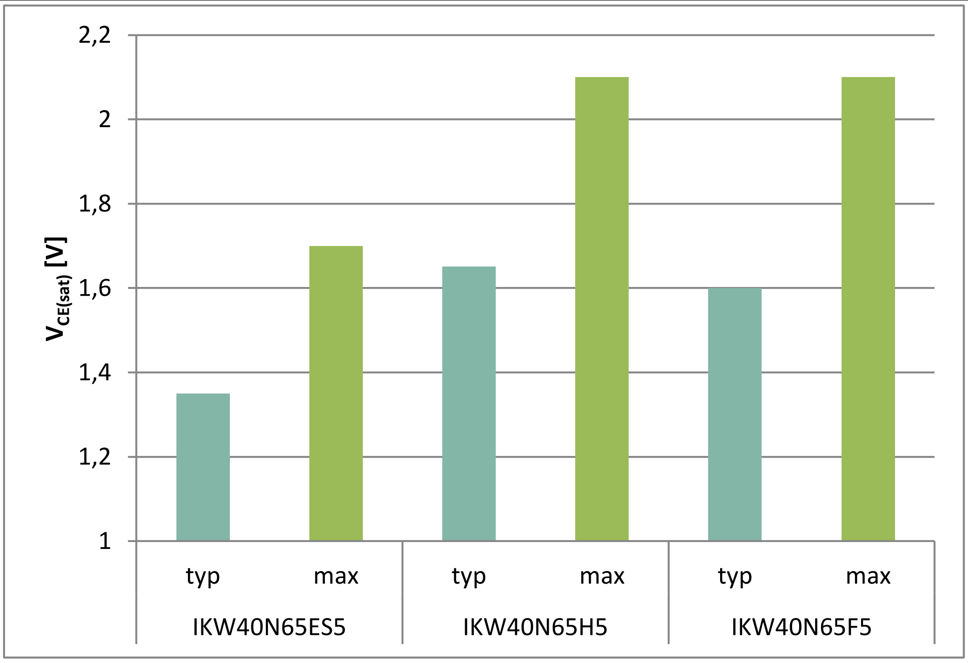


Figure 6 $V_{CE(sat)}$ at 25°C, typical and maximum values

3 Switching performances

High speed technology does not automatically mean best performance in real applications. It should be considered that in most of the cases it is not always possible to simply replace the former Infineon Technologies, without any layout improvement. This is especially true when using the fast TRENCHSTOP™ 5 IGBT versions like F5, WR5 and H5. In such cases, PCB layout design must have an extremely narrow current compensation path to get the lowest parasitic inductance in both, power- and signal-path. Alternatively, specific gate network or split gate resistances are required.

All these arrangements are obsolete with the new S5 IGBT. This technology allows a simple 1:1 replacement with the former HighSpeed 3 technology, even using the same gate resistance. No need of complicated passive gate networks, no expensive clamping circuitry on the collector.

An example of the different dynamic behavior is reported in the Figure 7 and Figure 9. Figure 7 shows a direct comparison of the turn-off behavior of an S5 in comparison with an H5 and to a former TRENCHSTOP™ IGBT in a double pulse test having a stray inductance of about 35 nH. The junction temperature is T_{vj}=25°C and the gate resistance is R_G=10.2 Ω in both cases. Solid lines depict the H5 behavior, dashed lines show the S5 and dotted lines finally show the former Trench IGBT dynamic behavior in turn-off.

Collector current of the S5 shows a lower di/dt, which leads to a reduction of the overshooting voltage of about 70 V in this case. In Figure 8, we have collector current I_C, 10 A/div. Collector to Emitter voltage, V_{CE}, 100 V/div. Gate to Emitter voltage, V_{GE}, 10 V/div. turn-off switching losses, E_{off} 100 µJ/div. Time scale 100 ns/div.

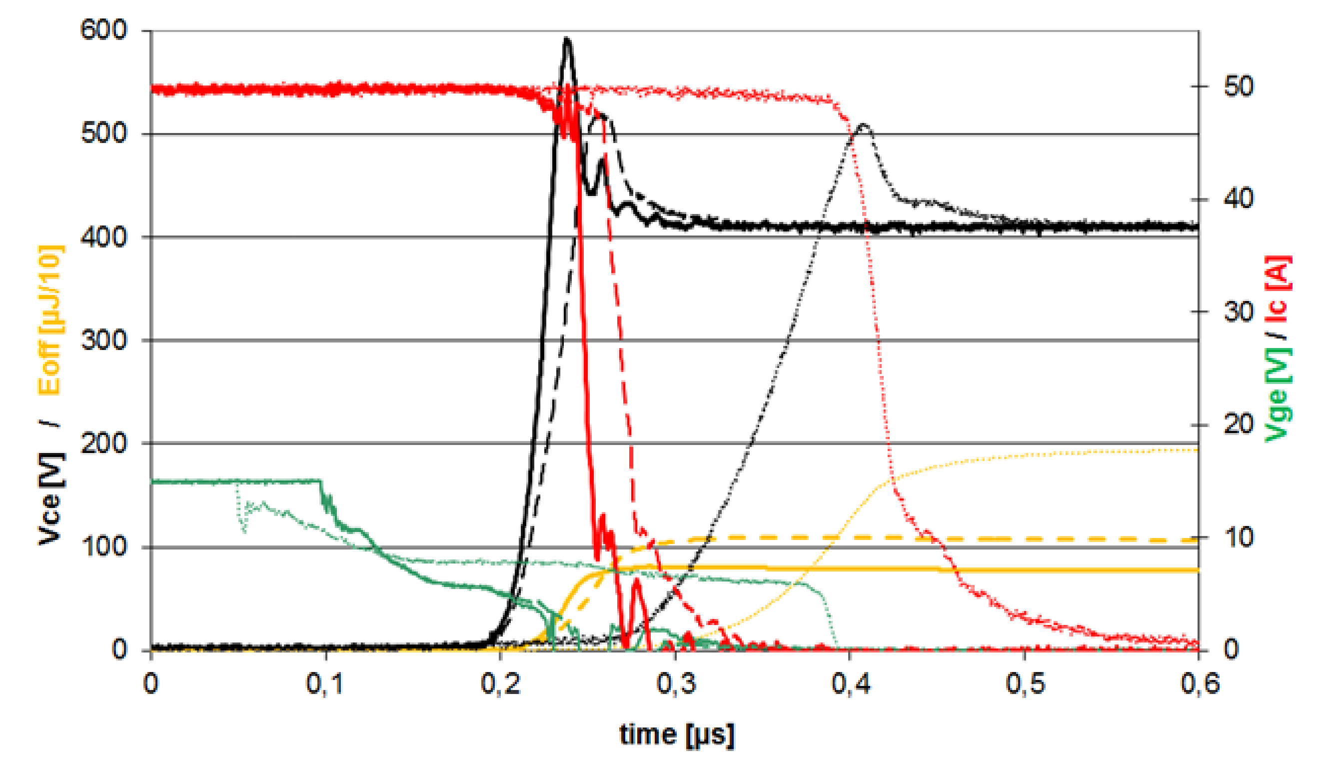


Figure 7 Switching behaviour comparison between IKW50N65H5, solid lines, IKW50N65ES5, dashed lines, and IKW50N60TA, dotted lines

The same behavior is reported in real applications. Tests have been carried out on IKW40N65ES5 measured using an in-house welding test bench as can be seen in Figure 8. It is a single phase Manual Metal Arc (MMA) welding machine 4.5 kW Infineon-TF1 Half-Bridge testing demonstrator at L_σ≈90 nH and f_{sw}=38 kHz. Testing conditions include: T_{amb}=23°C, T_{vj}=T_{amb}, $R_{g(on)}$=22 Ω, $R_{G(off)}$=33 Ω, I_{out}=157 A_{DC}, I_C=33 A.

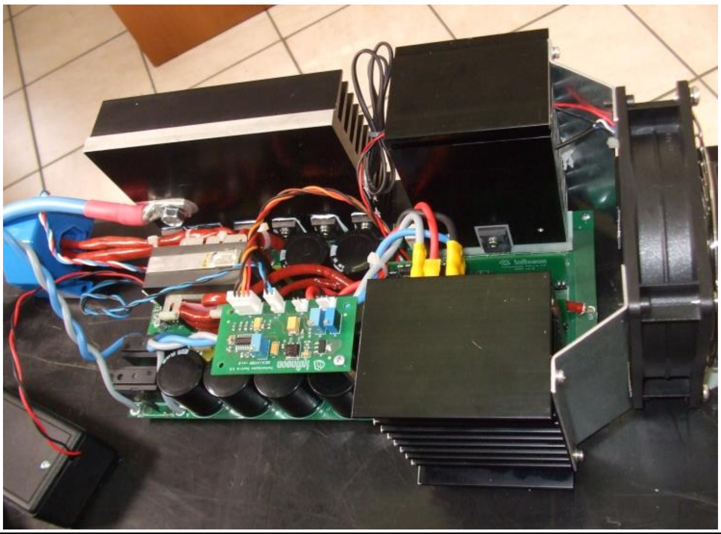


Figure 8 Infineon-TF1 4.5kW half-bridge, MMA/TIG welding machine demonstrator

Switching performances

The switching behavior is displayed in Figure 10. I_C, V_{CE} and V_{GE} waveforms in a time scale of 100 ns for a fast WR5 IKW40N65WR5 and the equivalent S5 version IKW40N65ES5 are compared. Voltage overshooting has been reduced, in the same testing condition, by about 35%. Beside this difference, another relevant aspect to be noted is the characteristic of the overshooting and the lower dv/dt, with about 30% reduction. I_C at 10 A/div. V_{CE} at 100 V/div. V_{GE} at 7 V/div. P_D at 2 kW/div. E_{off} is calculated as integral of the Power P_D and the result is detailed in the chart. Time scale for all waveforms is t=100 ns/div.

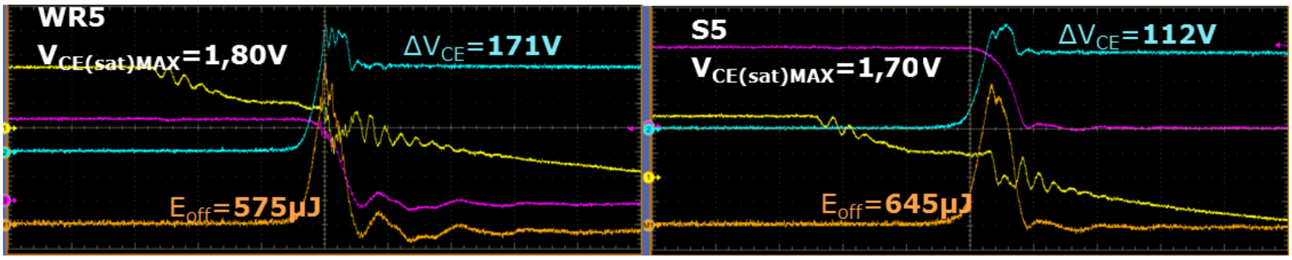


Figure 9 Comparison of the switching behavior between (a) IKW40N65WR5 and (b) IKW40N65ES5.

Another comparison is shown in Figure 11. I_C, V_{CE} and V_{GE} behavior in a time scale of 100ns related to two competitors' devices from top to bottom, Comp1 and Comp2 and the equivalent S5 version IKW40N65ES5 are highlighted. I_C at 10 A/div; V_{CE} at 100 V/div; V_{GE} at 7 V/div; P_D at 2 kW/div, E_{off} is calculated as integral of the power P_D and the result is depicted in the chart. A strong reduction in the voltage peak during turn-off can be noted. The softer behavior of the voltage overshoot at turn-off and the lower slew rate are even more evident than in the case of Figure 10.

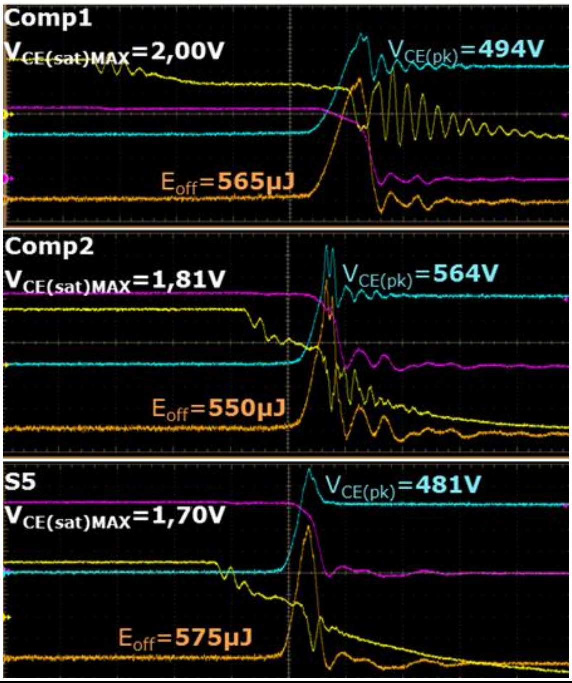


Figure 10 Comparison of the switching behavior between two competitors' devices and an IKW40N65ES5 (from top to bottom)

3.1 Safe operating areas

As per IEC 60747 3.3.14, Safe Operating Areas (SOA) is a chart of collector current versus collector emitter voltage where the IGBT is able to turn-on and turn-off without failure. It is possible to distinguish:

- Forward bias safe operating area (FBSOA), as per IEC60747-9 3.3.14.1. This is the collector current versus collector emitter voltage area which the IGBT is able to turn-on and is able to be in on-state without failure.
- Reverse bias safe operating area (RBSOA) as per IEC 60747-9 3.3.14.2. is the collector current versus collector emitter voltage area where the IGBT is able to turn-off without failure.
- Short Circuit safe operation area (SCSOA)

Figure 11(a) display the Forward Bias Safe Operating Area (FBSOA) of an IKW50N65H5.

Although short excursions into the active region might be allowed within TRENCHSTOP™ 5 technologies, it is strongly recommended to operate these IGBT families as a switch-mode only and to use it in active region only during commutation transients. Indeed, it is not recommended to operate TRENCHSTOP™ 5 IGBT continuously in linear- or active amplification mode, to avoid local overload due to the variation in the transfer characteristic of the IGBT cells or paralleled chips. Therefore, the diagonal lines - at constant power dissipation per pulse duration and especially the DC-mode operation typical for the former IGBT technologies are no longer suggested as continuous working conditions. For the S5 version the FBSOA chart is no longer available since it is considered a full square, limited by the maximum forward power dissipation, caused by $V_{CE(sat)}$ and by the $I_{C(pulse)}$ limited by $T_{vj(max)}$.

In such case for the S5 version, due to additional specific measures, the FBSOA has been extended up to 4 times the nominal collector current; while for the H5 version, this is only performed upon specific requests.

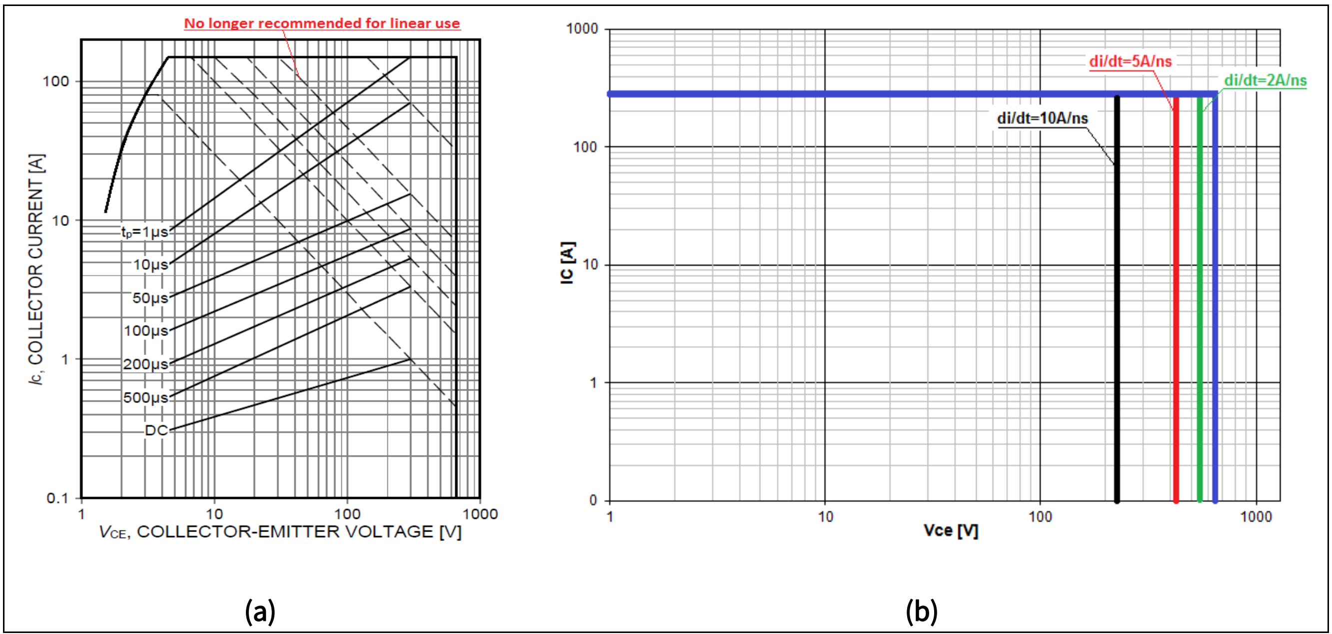


Figure 11 (a) IKW50N65H5 Forward Bias Safe Operating Area. (b) Reverse Bias Safe Operating Area (RBSOA), showing the limitations introduced by collector to emitter parasitic inductance -in this case considering a layout with total L_σ=40 nH.

Figure 11 (b) depicts an example of a Reverse Bias Safe Operating Area (RBSOA). Also in this case, for the S5 version, the RBSOA has been extended up to four times the nominal current. Indeed, TRENCHSTOP™ 5 IGBT technology may operate at max I_C up to three times the nominal current. However, due to the stray inductance limitations, it might be not possible to turn-off without maximum V_{CEs} being exceeded. In this case, a layout with a total stray inductance of L_{σ}=40 nH has been considered. This leads to potential SOA limitations, especially when running large current and high level of fall times, in general with di/dt at above 3...7 kA/µs.

Such current levels in the H5, F5 and WR5 versions might be achieved only using adequate layout solutions or appropriate countermeasures like layout improvements, reduced DC Link voltage, introduction of active clamping, using larger R_G - slower and softer turn-off and/or only in case no other countermeasures work, using specific turn-off stress relief circuits. All these arrangements might not be necessary when using an S5 IGBT version, having lower di/dt and therefore self-limiting characteristics regarding the voltage overshoots at turn-off.

4 Application example, design hints and recommendations using the TRENCHSTOP™ 5 S5 IGBT version

As mentioned in Chapter 3, TRENCHSTOP™ 5 S5 exploits the same technological approach as the former H5 version but it uses a backside emitter that experienced stronger annealing. This allows reaching similar switching performance as the H5 IGBT, thanks to a simple gate resistance adjustment due to the much smoother behavior.

Although switching losses using the nominal gate resistor R_G are slightly increased compared to the H5, the softer commutation behavior of the S5 allows using a much smaller gate resistance keeping the same voltage overshoot at turn-off. In such case, it is possible to maintain similar switching losses in comparison with the H5 and to get a large benefit in total losses reduction due to the significant reduction of the forward voltage $V_{CE(sat)}$ by 18%; the value changes down to 1.35 V against the 1.65 V of the H5.

To maintain a maximum voltage overshoot of 80% $V_{(BR)CEs}$ or 520 V, the H5 would require a gate resistance of 27 Ω, as seen in Figure 12(a), while the S5 only a 4,7 Ω. In such conditions, as shown in Figure 12(b), the turn-off losses will result in the range of 1.2 mJ for the S5 and about 1.3mJ for the H5. The turn-on losses of the S5, as shown in Figure 12(c), will be reduced in comparison to the H5 by about 42%. This leads to a significant reduction in the total losses for the S5 by about 26%.

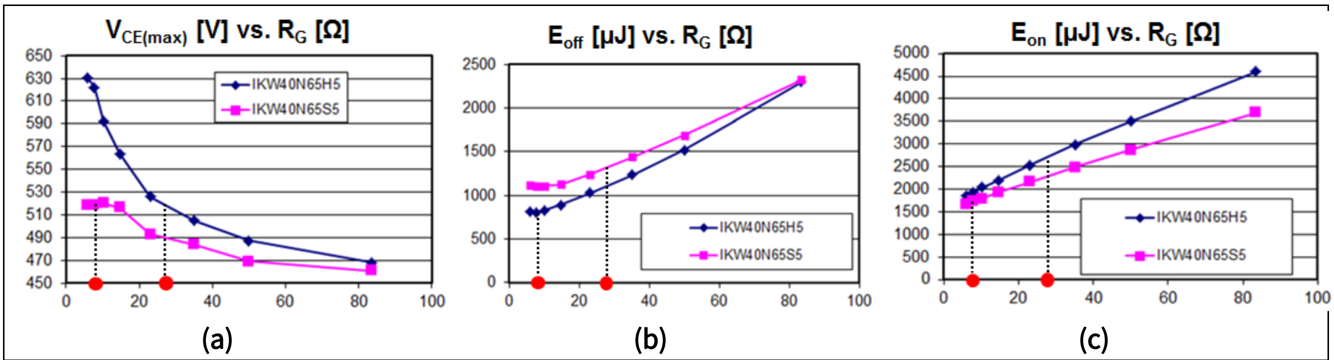
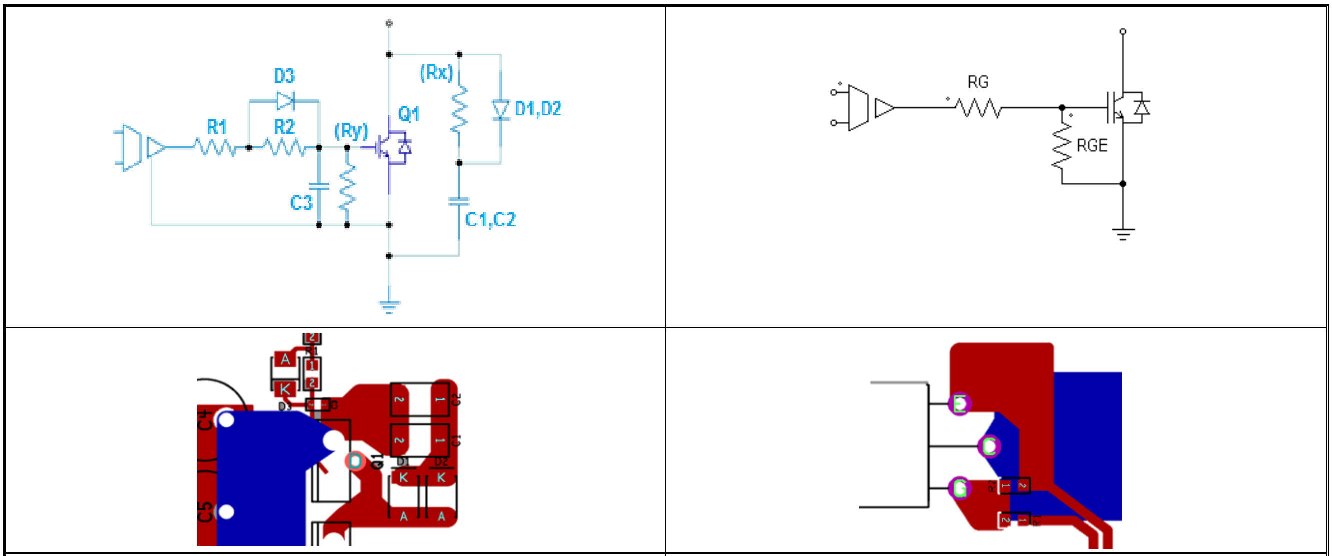


Figure 12 Selection of a lower gate resistance value with S5 is possible compared to H5. (a) $V_{CE(max)}$ is set at 520 V, it is possible to select 4.7 Ω for the S5 and 27 Ω for the H5. Using these R_G values, the S5 has 8% lower E_{off} (b) and 42% lower E_{on} (c).

The simplification of the input circuitry, using a single gate resistance approach, is depicted in Figure 13. Figure 13(a) displays a recommended solution with a possible clamping network and eventual electrical stress relief circuitry to be placed as close as possible to the IGBT/FWD for the IKW50N65H5 and the related PCB routing circuitry. Figure 13(b) describes the single gate resistance approach for a typical S5 application and the simplification of the PCB routing which is possibile to achieve with S5 accordingly.



(a) (b)

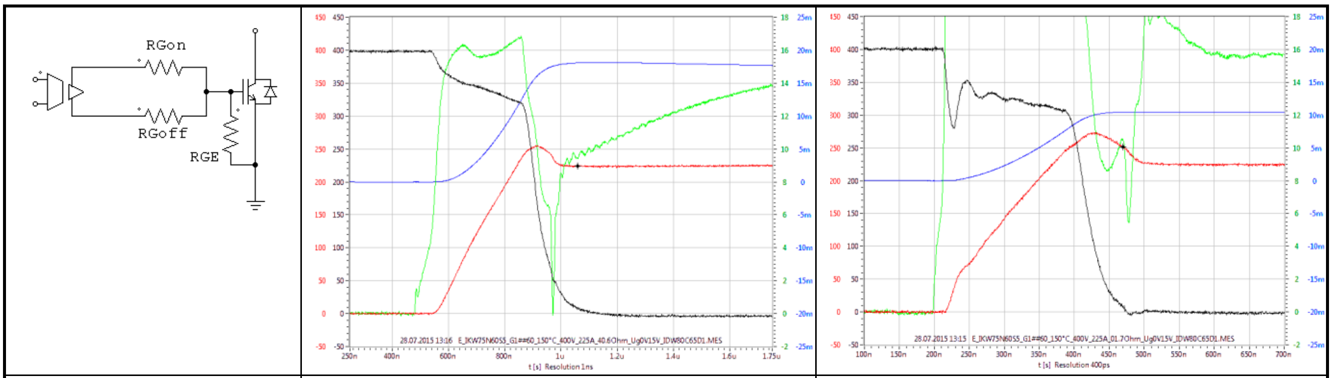
Figure 13 (a) recommended solution with a possible clamping network for the H5, F5 and WR5 TRENCHSTOP™ 5 versions and related PCB routing. (b) Schematic of the recommended solution for the S5 version with the related PCB routing simplification

Another important aspect, relevant in several applications, is related to the case of large currents commutated in very short time. This is only the case with the IKW75N65ES5 when used with very large collector currents and when using a small gate resistance.

In this situation, the di/dt in turn-on, due to very short rise time, might be extremely high and result in a challenge for the Rapid 1 diode in antiparallel used for free-wheeling. In this extreme situation and only for this component of the S5 series, it is recommended to split the gate resistance in $R_{G(on)}$ and $R_{G(off)}$, increasing the $R_{G(on)}$ in comparison to the suggested nominal gate resistance value.

The value of this resistance is related to the stray inductance of the circuit and to the di/dt reached during the commutation. For a parasitic inductance of 30…40 nH, it is recommended to increase the gate resistor $R_{G(on)}$ up to 3 times the nominal gate reisistance value, while for a stray inductance above 50…60 nH, an increase of $R_{G(on)}$ up to 5 times might be necessary.

Figure 14 (c) displays an example of a switching event using a IKW75N65ES5 which is commutating a collector current of 225 A representing three times the nominal current with a gate resistance of 1.7 Ω in a very low stray inductance environment of about 30 nH. Figure 14(b) the same characteristics is depicted, using a gate resistance of 40.6 Ω. In order to compensate the obvious increase in the switching losses, in this case about 34%, it is suggested to split the gate resistance and to select the nominal R_G value for the turn-off: $R_{G(off)}$. In this case the circuit is sketched in Figure 14 (a).



(a) (b) (c)

Figure 14 (a) Example of split gate resistance circuit to be adopted only in case of IKW75N65ES5 used at very large collector current and large stray inductance. (b) Turn-on waveforms: V_{CE}, 50 V/div; V_{GE}, 2 V/div; I_C, 50 A/div; E_{off}, 5 mJ/div, time 200 ns/div, using an $R_{G(on)}$=40.6 Ω. (c) Turn-on waveforms: V_{CE}, 50 V/div; V_{GE}, 2 V/div; IC, 50 A/div; E_{off}, 5 mJ/div, time 50 ns/div using an $R_{G(on)}$=1.7 Ω.

Finally, as with other TRENCHSTOP™ 5 technologies, it is worth to mention the minimum turn-on time to avoid EMI problems. To reach a relatively soft switching, the charge carriers of a bipolar device like diode, BJT or IGBT, must be granted sufficient time to reach the state of quasi-static charge carrier distribution. This is not the case for very short conduction times. The high-frequency oscillations which may be triggered because of this reason can influence signals and logic devices. This may significantly impair a safe and reliable operation. Furthermore it should be considered that, owing to the lower mobility of charge carriers, this effect is particularly strong at high temperatures, especially when approaching the 150°C junction temperature.

Unfortunately in a data sheet for a discrete component, the minimum turn-on time cannot be specified like in a power module for example, as the magnitude and the frequency of the oscillations strongly depends on the parasitic components of the PCB routing itself. This mainly considers the stray inductances but parasitic capacitances and resistances as well. As a very general recommendation when using TRENCHSTOP™ 5 S5 IGBT version, it is suggested to cancel extremely short pulse signals in the PWM pattern, especially the ones well below 1 µs.

5 References

[1] D. Chiola, H. Hüsken, T. Kimmer: *"High Speed IGBT with MOSFET-like switching behavior"*, Proceedings PCIM China, Shanghai 2010.

[2] T. Kimmer, E. Griebl: *"TRENCHSTOP™ 5: A New Application Specific IGBT Series"*, Proceeding PCIM Europe, Nuremberg 2012.

[3] F. Brucchi: *"Effect of Parasitic Parameters on Switching Characteristics and SOA of the TRENCHSTOP™5 IGBT"*. Proceeding PCIM Europe, Nuremberg 2013.

6 Useful material and links

IGBT web page: http://www.infineon.com/igbtdiscretes

- Contains application note and spice models for discrete IGBT

TRENCHSTOP™ 5 S5 web page: http://www.infineon.com/trenchstop5-S5

This page will include:

- Product Technical Description
- Use in Application
- Assembly Details
- Product Brief
- Datasheets

7 Revision History

Major changes since the last revision

Page or Reference	Description of change
Revision 1.0	First Release

Trademarks of Infineon Technologies AG

AURIX™, C166™, CanPAK™, CIPOS™, CIPURSE™, CoolMOS™, CoolSET™, CORECONTROL™, CROSSAVE™, DAVE™, DI-POL™, EasyPIM™, EconoBRIDGE™, EconoDUAL™, EconoPIM™, EconoPACK™, EiceDRIVER™, eupec™, FCOS™, HITFET™, HybridPACK™, I²RF™, ISOFACE™, IsoPACK™, MIPAQ™, ModSTACK™, my-d™, NovalithIC™, OptiMOS™, ORIGA™, POWERCODE™, PRIMARION™, PrimePACK™, PrimeSTACK™, PRO-SIL™, PROFET™, RASIC™, ReverSave™, SatRIC™, SIEGET™, SINDRION™, SIPMOS™, SmartLEWIS™, SOLID FLASH™, TEMPFET™, thinQ!™, TRENCHSTOP™, TriCore™.

Other Trademarks

Advance Design System™ (ADS) of Agilent Technologies, AMBA™, ARM™, MULTI-ICE™, KEIL™, PRIMECELL™, REALVIEW™, THUMB™, µVision™ of ARM Limited, UK. AUTOSAR™ is licensed by AUTOSAR development partnership. Bluetooth™ of Bluetooth SIG Inc. CAT-iq™ of DECT Forum. COLOSSUS™, FirstGPS™ of Trimble Navigation Ltd. EMV™ of EMVCo, LLC (Visa Holdings Inc.). EPCOS™ of Epcos AG. FLEXGO™ of Microsoft Corporation. FlexRay™ is licensed by FlexRay Consortium. HYPERTERMINAL™ of Hilgraeve Incorporated. IEC™ of Commission Electrotechnique Internationale. IrDA™ of Infrared Data Association Corporation. ISO™ of INTERNATIONAL ORGANIZATION FOR STANDARDIZATION. MATLAB™ of MathWorks, Inc. MAXIM™ of Maxim Integrated Products, Inc. MICROTEC™, NUCLEUS™ of Mentor Graphics Corporation. MIPI™ of MIPI Alliance, Inc. MIPS™ of MIPS Technologies, Inc., USA. muRata™ of MURATA MANUFACTURING CO., MICROWAVE OFFICE™ (MWO) of Applied Wave Research Inc., OmniVision™ of OmniVision Technologies, Inc. Openwave™ Openwave Systems Inc. RED HAT™ Red Hat, Inc. RFMD™ RF Micro Devices, Inc. SIRIUS™ of Sirius Satellite Radio Inc. SOLARIS™ of Sun Microsystems, Inc. SPANSION™ of Spansion LLC Ltd. Symbian™ of Symbian Software Limited. TAIYO YUDEN™ of Taiyo Yuden Co. TEAKLITE™ of CEVA, Inc. TEKTRONIX™ of Tektronix Inc. TOKO™ of TOKO KABUSHIKI KAISHA TA. UNIX™ of X/Open Company Limited. VERILOG™, PALLADIUM™ of Cadence Design Systems, Inc. VLYNQ™ of Texas Instruments Incorporated. VXWORKS™, WIND RIVER™ of WIND RIVER SYSTEMS, INC. ZETEX™ of Diodes Zetex Limited.

Last Trademarks Update 2011-11-11

www.infineon.com

Edition 2014-11-24

Published by

Infineon Technologies AG

81726 Munich, Germany

Do you have a question about any aspect of this document?

Email: erratum@infineon.com

AN2015-15

Legal Disclaimer

THE INFORMATION GIVEN IN THIS APPLICATION NOTE (INCLUDING BUT NOT LIMITED TO CONTENTS OF REFERENCED WEBSITES) IS GIVEN AS A HINT FOR THE IMPLEMENTATION OF THE INFINEON TECHNOLOGIES COMPONENT ONLY AND SHALL NOT BE REGARDED AS ANY DESCRIPTION OR WARRANTY OF A CERTAIN FUNCTIONALITY, CONDITION OR QUALITY OF THE INFINEON TECHNOLOGIES COMPONENT. THE RECIPIENT OF THIS APPLICATION NOTE MUST VERIFY ANY FUNCTION DESCRIBED HEREIN IN THE REAL APPLICATION. INFINEON TECHNOLOGIES HEREBY DISCLAIMS ANY AND ALL WARRANTIES AND LIABILITIES OF ANY KIND (INCLUDING WITHOUT LIMITATION WARRANTIES OF NON-INFRINGEMENT OF INTELLECTUAL PROPERTY RIGHTS OF ANY THIRD PARTY) WITH RESPECT TO ANY AND ALL INFORMATION GIVEN IN THIS APPLICATION NOTE.

Information

For further information on technology, delivery terms and conditions and prices, please contact the nearest Infineon Technologies Office (www.infineon.com).

Warnings

Due to technical requirements, components may contain dangerous substances. For information on the types in question, please contact the nearest Infineon Technologies Office. Infineon Technologies components may be used in life-support devices or systems only with the express written approval of Infineon Technologies, if a failure of such components can reasonably be expected to cause the failure of that life-support device or system or to affect the safety or effectiveness of that device or system. Life support devices or systems are intended to be implanted in the human body or to support and/or maintain and sustain and/or protect human life. If they fail, it is reasonable to assume that the health of the user or other persons may be endangered.